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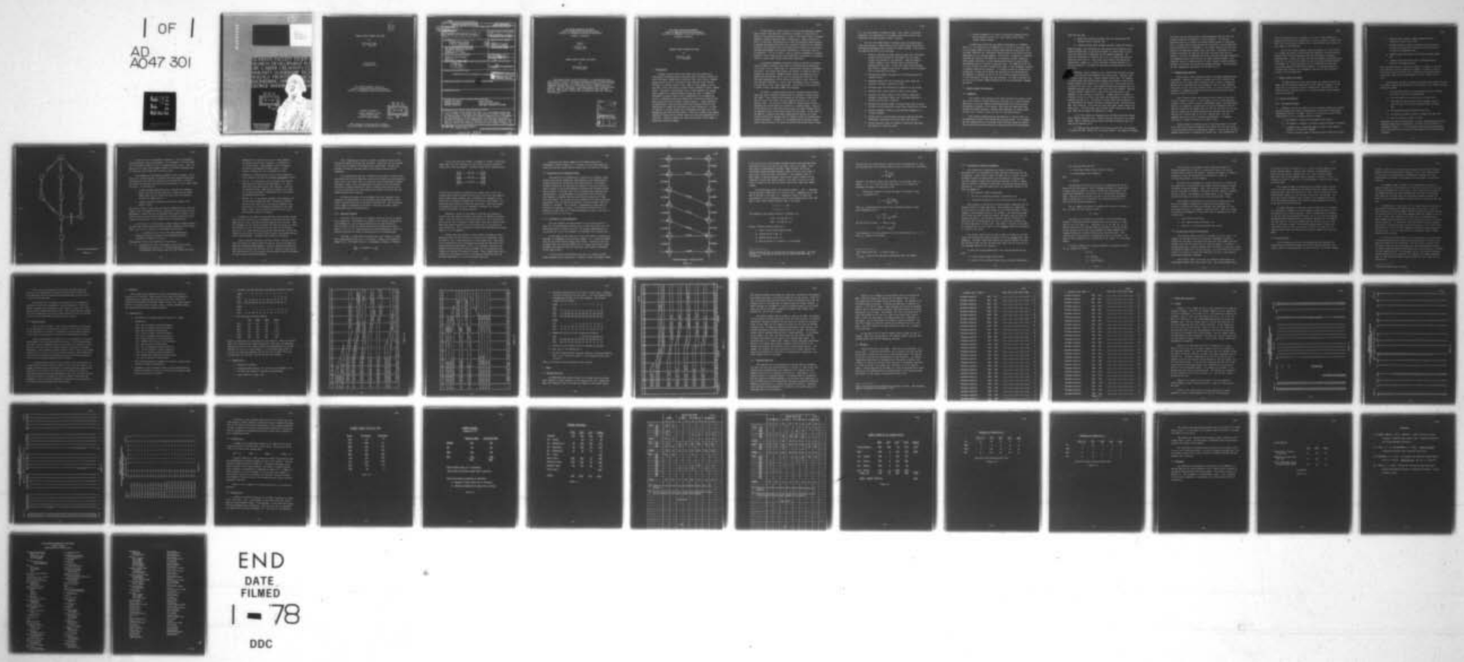

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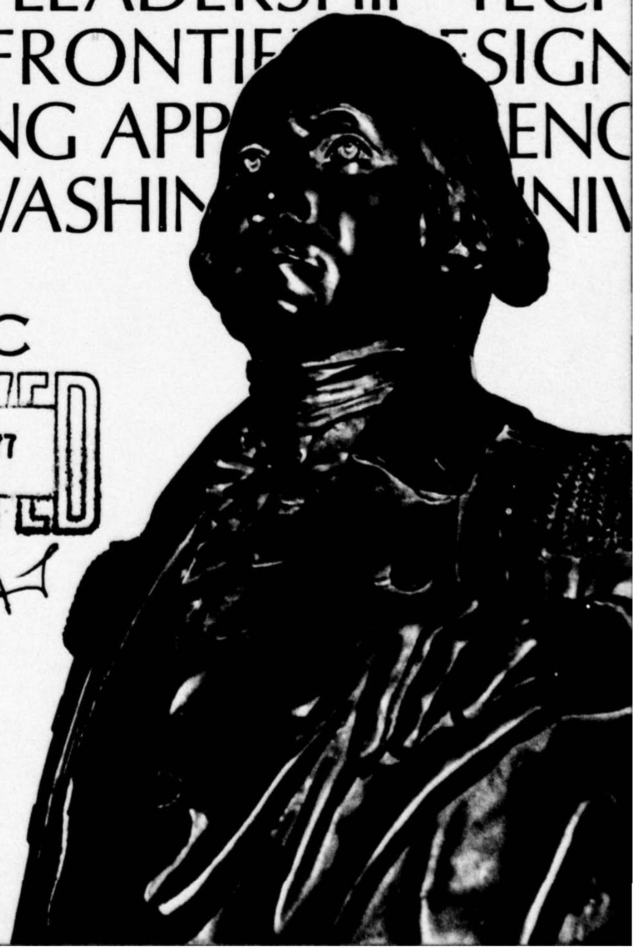

INSTITUTE FOR MANAGEMENT
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DYNAMIC FLIGHT STUDENT FLOW MODEL

by

William E. Caves
W. L. Wilkinson

Serial T-362
21 October 1977

The George Washington University
School of Engineering and Applied Science
Institute for Management Science and Engineering

Program in Logistics

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The Dynamic Flight Student Flow Model is a time-weighted capacitated network on which an optimizing algorithm operates to produce minimum time-to-train solutions. The model will provide an improved tool in the management and planning for an efficacious flow of students both with respect to internal efficiency of the Undergraduate Pilot Training Program and with regard to the external impact of different input and output policies. The numerical results and conclusions are given for two realistic scenarios.

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1. Introduction

Changes in policy dictated by higher authority coupled with fluctuations in Congressionally authorized funds, available training aircraft, PCS funds, student pilot accessions, Fleet force levels, squadron manning levels and pilot continuation rates have kept Naval Aviation Training in a constant state of flux. Many of these changes occur on very short notice and require an almost instant response at senior command levels. The present system handles each of these demands on an *ad hoc* basis, generally by sending requests through the chain of command for statements of expected impacts and recommendations for accommodating action. Accommodating plans are based mostly on intuition garnered from long association with the flight training community. Impact statements are generated for these intuitive plans after long and laborious hand computation of student flow resulting from these assumptions. In order to respond in the time allowed, most calculations are based upon broad assumptions and crude planning factors. Results are equally crude approximations of impact and are neither subject to audit nor reproducible at a later date. Predicted impacts are thus often accorded little weight by authorities directing changes.

The application of ADPE, coupled with a data base generally acknowledged to have a high degree of credibility, provides the opportunity to develop a quick-response capability to react to precipitous real or proposed changes in training resources and/or training rate. Timely solutions to "what if" questions, characterized by a clear and defensible identification of maximum achievable production rates, necessary reallocation of available resources, and attendant costs can provide senior echelons in the Naval Air Training Establishment the necessary information to effectively ward off the haphazard - cut till it hurts - type of arbitrary management of budgets. Similarly, these solutions will allow quantitative comparison of alternative courses of action under current operational constraints.

An automated management information system is viewed as a coherent family of models covering a wide range of considerations and objectives. In no sense is such a system seen as a "push button" solution to management situations. The system would project the results of a plan but does not produce the plan itself. Managers should continue to manage and such a system will provide much better tools for getting their job done. The effective implementation of the system would require a staff member to have intimate knowledge of a model's data requirements and its treatment of those data to meet certain objectives. As one step in this direction, a Dynamic Student Flow Model (DSFM) was developed.

The DSFM is a computer-based system for producing flight student input and output schedules including data for analyses of internal pipeline flows. These schedules are produced for an arbitrary time period, say five years, and reflect the given planning criteria, e.g., level monthly output. The structure of the DSFM is a network where the arcs represent the various phases and locations of training phases. Every arc in the network has a time duration and capacity-to-train parameter which is applicable at the actual week of entry into the phase. At the heart of the DSFM is a rigorous, well-known algorithm which ensures that every solution delivers the maximum output of graduates under the stated conditions (constraints). Moreover, of all maximum output solutions (should there be more than one), the given solution has the minimum time-to-train,

i.e., the least amount of student pooling. With respect to these two properties, any requirements or performance projections would be very defensible even under the most critical scrutiny.

The use of the DSFM through a responsive data processing system would give the Navy a common structure for discourse among the different planning and management levels involved in flight training. Some particular capabilities would be the following.

a. Produce a schedule of student inputs by week over a five-year projected period stating the requirements for an optimal student flow through all the pipelines. When the expected scenario changes, a new schedule could be produced with minimum effort and time. If only the annual Pilot Training Rate (PTR) is changed, then the new schedule could be produced with no additional staff effort.

b. Determine the maximum throughput of the training system for a given scenario.

c. Determine capacity-to-train required by weeks, phase and location to produce a given set of PTRs.

d. Determine where the training bottlenecks are in the system.

e. Determine where excess capacities exist in the system.

f. Determine the surge capacity of the system if additional personnel, spare parts, funds, etc., were made available to increase the aircraft utilization.

g. Determine the expected number of student-weeks spent in pools and their location which will result from a given plan or policy.

h. Provide information leading to improved PTR assignments to training commands.

i. Provide data for staff analysis leading to improved pipeline balancing of capacities-to-train by phase and location.

j. Provide expected tracks for students to follow as they enter the system at a particular week.

k. Provide a measure of the effect of different planning policies and scheduling criteria, e.g., level input, level output, uniform student loading.

A related local effort was the separate development of a HOWGOZIT Model [1]. The objective of the HOWGOZIT is to provide an evaluation (HOW) of the progress (GOES) of pilot training toward meeting planned goals (IT). The model identifies the constraining resource based on the actual operating experience of each training squadron. With forecast information of expected workloads and projected availabilities of resources, squadron commanders should permit operations to avoid impending bottlenecks by accelerating or decelerating rates of training at opportune times. The HOWGOZIT should act to locate critical and slack resources and assist in any realignment necessary to minimize underutilized resources. It provides a method of comparing the productivity of wings and pipelines and verification of planning factors. The HOWGOZIT is designed for the use of the training command headquarters and the subordinate training wings and squadrons. The DSFM is designed for the use of the training command headquarters and the superordinate commands and staffs.

2. Dynamic Student Flow Approach

2.1 Background

This research was motivated in the early seventies by a desire on the part of the Aviation Training Division in the Office of the Chief of Naval Operations to find some improved scheduling methods which would minimize the pooling of students in the system. Since there are associated costs incurred by student pooling, a schedule which minimizes the student weeks in pools can, in effect, reduce the cost to train Naval Aviators.

This research demonstrated the applicability of network theory in the modeling of student flows through the training process. As an example, the jet training portion of the Naval flight training program was modeled and two solutions based upon different scheduling policies were generated.

These policies were:

A. given input schedule (constant rate) and given monthly PTR schedule (nearly uniform), and

B. solution derived input schedule and given annual PTR schedule.

These solutions, each delivering the same annual pilot production rate, differed significantly in the required number of student weeks in pools and in the mean time-to-completion for the students graduated. The variation in meantime to train was about 2.3% (1.7 weeks) with policy B being less than policy A. Thus, those costs directly associated with maintaining a student; i.e., hotel facilities, student salaries, etc.; could be reduced by 2.3% simply by selecting one scheduling policy over the other.

Defining a "good" schedule is not a simple task for there are many constraints over which the scheduler has little control. However, there are certain properties that a "good" schedule should have. For example, it should accept the predicted input schedule for whatever it may be and produce graduate Naval Aviators at a required rate. Quite often, this is a uniform rate over a year. From flight training, most graduates go on to Readiness Squadrons which prefer their input rate to be uniform. Moreover, a nearly constant student load at each of the training bases is very desirable in the interests of efficiency. Student load is the number of students on board at a base at any given time independent of what state of training they may be in. Variations in student loads mean variations in the requirements for messing, berthing, training aircraft, instructors and many other resources. To provide for peak loads means unused resources at other times. A uniform output and a uniform student load are at odds with each other and the region for compromise is large.

It is in the region for compromise that the DSFM can aid the planner where feasible solutions exist. However, feasible solutions do not always exist. When no feasible solution exists the DSFM can indicate where and when the bottlenecks occur.

The DSFM has been exercised over the years since 1971, as requested, to project the PTRs, usually over a five-year period. All phases of training

from entry into the Primary Phase through graduation from the Jet, Prop and Helo pipelines were modeled for these exercises. The starting conditions were set to reflect the onboard student loads on a particular date. A typical result would disclose that shortfalls in the planned PTR could be expected for the remainder of the current year and the next year because of an imbalanced student load at the start. Thereafter, the input schedule derived by the model was such that the planned PTRs would be realized. In 1976, the DSFM was used in two scenarios covering hypothetical realignments of major proportions to the flight training process. Both scenarios involve a transition period of base closures, squadron decommissionings, new syllabi and aircraft and squadron movement. This was easily the most comprehensive application of the DSFM to date.

2.2 Transportation Networks

There exists a large theoretical base of knowledge regarding flows in networks. Basically, a network is defined as a set of points called nodes and a set of links, each connecting a pair of points, called arcs. Network flow is then defined as the movement of units of some commodity from point to point along the available links. It is this concept of the movement of a commodity through the network from which the term "transportation network" is derived.

Much of network theory was developed in the context of the point-to-point shipment of goods. In this context the set of nodes generally consists of three classes; sources, transshipment points, and destinations. Further, two parameters, capacity and cost, may be assigned to each arc. Capacity is given as the maximum units of flow that can move over the arc and cost is given as the penalty incurred when moving one unit of flow from the arc's initial node to the arc's terminal node. The cost parameter may have any one of several interpretations. As examples, cost may be in terms of dollars or in terms of time.

Having defined the network as above, the problem then is to establish a set of arc flows which maximize the network flow from the sources to the destination without exceeding the capacity of any arc and, for this maximal network flow, to minimize the overall cost. This minimization of

cost is of interest since, in general, a set of arc flows forming the maximal network flow is not unique and all such sets are not of equal cost. Such a set of arc flows is referred to as a max-flow/min-cost solution or, more simply, a flow solution.

For all but trivial networks, the establishment of a flow solution is a lengthy and arduous process beyond the capability of manual methods; however, many efficient algorithms have been developed for computer implementation. Some of these are the Ford and Fulkerson max flow/min cost (F&F) [2], the Out-of-Kilter (OOK) [2], and the Universal Maximal Dynamic Flow (UMDF) [3]. These algorithms are well established and have been successfully applied to many varied problems. The system described by his paper and upon which the experimental results are based utilizes a version of the F&F algorithm.

3. Dynamic Student Flow Model

The DSFM consists of three basic phases; the network construction phase, the flow insertion phase and the report generation phase. In the sequel will be discussed the network construction, calculation of arc parameter values, representation of a five-year network, and the network preload and postload.

3.1 Network Construction

3.1.1 The Dynamic Network

Defining a network to model the flow of students through the training process requires that certain interpretations of the network terminology introduced in Section 2 be made. First, it is convenient to note certain characteristics of the training process as follows:

a. the commodity involved is the Student Naval Aviator,

b. the movement of students is through successive phases of training,

c. a student spends a specified number of weeks in each phase of training to which he is assigned,

d. students entering a phase of training during a week form a class,

e. students under training consume training resources resulting in finite class sizes.

f. students entering a phase of training for which there is no room in the next class formed are pooled until there is room in a subsequent class,

g. students enter the system at the initial (primary) phase, and

h. students leave the system either as designated Naval Aviators or through attrition.

Next, the objective may be stated as follows: to produce a flow solution which will accept a given input schedule of students or meet a given PTR at least cost where cost is defined as the overall time-to-train with a high penalty being assigned to student weeks spent in pools.

Having stated the above and ignoring attrition and student pools for the present, network terminology may be interpreted in the student training process as follows:

a. arcs represent phases of training, input paths of students, and output paths for system graduates;

b. the source node is the initial point of input arcs;

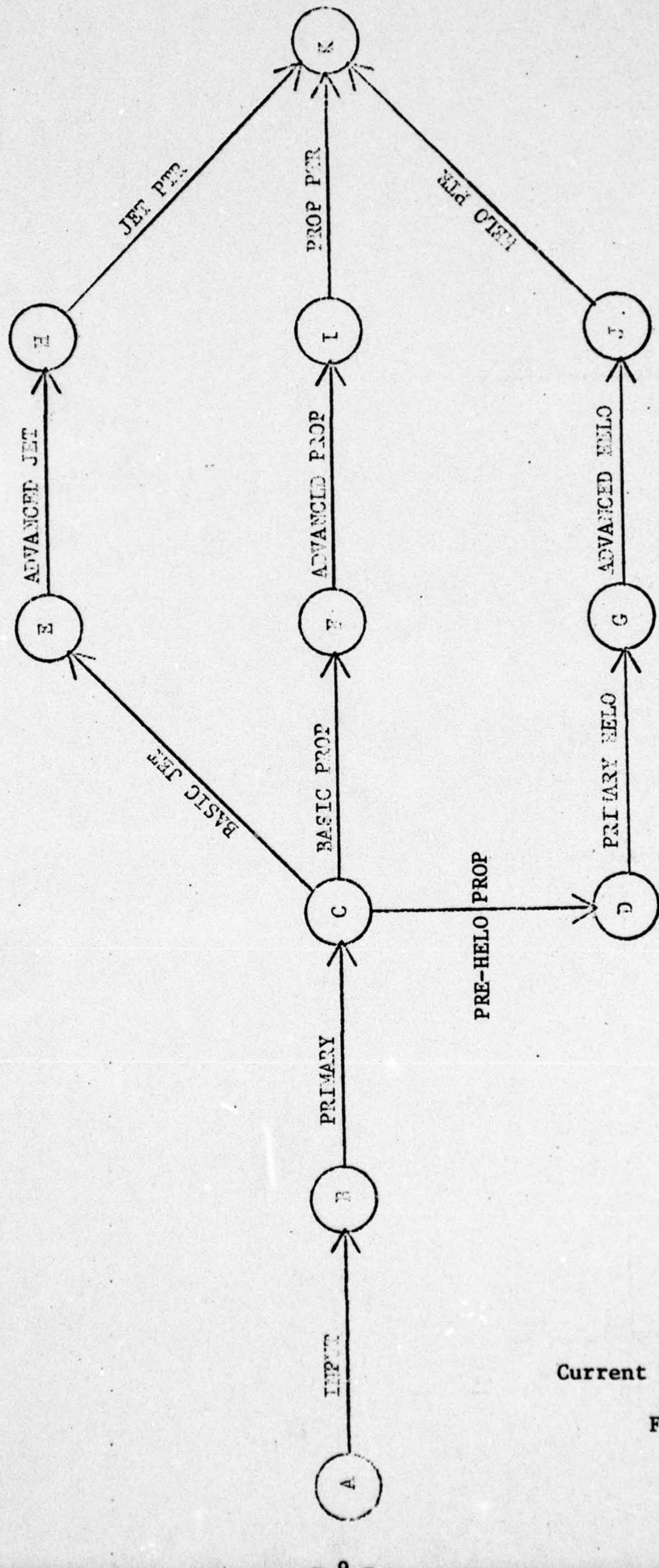
c. transshipment nodes are those which terminate phase or input arcs and also initiate subsequent phase or output arcs;

d. the destination node terminates output arcs;

e. arc capacity is given in units of students per week; and

f. arc cost is given in weeks to train.

Based upon the above interpretations, a network representing the current training process can be constructed. The form of such a network is diagramed in Figure 3.1. In this diagram the nodes have been assigned letter identifiers and the arcs have been labeled by the function they represent.



Current Training Network

Figure 3.1

To each of the arcs identified in Figure 3.1, the two parameters, cost and capacity, need to be assigned. The assignment of the cost parameter is relatively simple in that it represents time-to-train. Thus, for phase arcs its value is the length in weeks of the phase represented and for input and output (PTR) arcs its value is zero.

The assignment of the capacity parameter is not so simple. This is because the criteria applied to determine the values assigned depend upon the purpose for which the flow solution is to be generated. Basically, two options are available for each of the three groups of arcs; input, phase, and output. The options are:

a. utilize standard planning factors to establish the maximum phase class size for each phase arc, utilize the anticipated weekly input rate for input arcs, and utilize the required PTR rate for output arcs, or

b. assign a virtually unlimited value for one or more of the groups of arcs.

Care must be taken to ensure that the capacity parameter for at least one group of arcs is assigned according to option (a) or the solution will be meaningless. Before the user can determine which option to apply to each group of arcs for a particular execution of the model he must first have a basic understanding of a flow solution and its interpretation.

At this point in the discussion it seems prudent to detour slightly and make some further assertions and definitions regarding network theory. First, recall that in Section 2.2 the problem was defined as

> ". . . to establish a set of arc flows which maximize the network flow from the sources to the destinations without exceeding the capacity of any arc . . . ."

Keeping this in mind, the following are to be noted:

a. Conservation of flow: The algebraic sum of flow at transshipment nodes is zero, i.e., the flow entering a transshipment node exactly equals the flow leaving that node.

b. Feasible flow: The flow in an arc is never negative nor greater than the arc's capacity. In addition it is integer valued. (The parameters cost and capacity are given as non-negative integer values.) A flow solution consists of a set of feasible arc flows.

c. Constraint: Since the flow in an arc cannot exceed the arc's capacity, the capacity parameter constrains the flow.

d. Cut arc: If a solution is truly a maximal flow solution then some of the arcs will be capacitated, i.e., their flow value will exactly equal their capacity. Such arcs are called cut arcs. Note that the capacity of at least one of these arcs must be increased in order to increase the maximal network flow.

e. Network cut: In the network diagram a line crossing only cut arcs may be drawn such that it divides the network into two pieces with all of the sources contained in one piece and all of the destinations contained in the other piece. Such a line is called a network cut and, like a flow solution, need not be unique.

Returning to the subject of interpreting a flow solution, assume that the user's objective is to determine an input rate that will meet a given PTR rate with a specified training capacity for each phase. Then the assignment of the capacity parameter for phase and output arcs would be according to option (a) and for input arcs would be according to option (b). If, upon examining the resultant flow solution, all of the output arcs are found to be cut arcs then it meets the required PTR rate and is called feasible. Otherwise, the solution is infeasible.

Given a feasible solution in the above context, the flow in the input arcs gives the required input rate and th flow in the phase arcs gives the required training capacity. Given an infeasible solution, at least one of the phase arcs will be a cut arc. Phase arcs that are cut arcs indicate where in the system the training capacity must be increased in order to make the solution feasible.

Other combinations of capacity parameter assignment options may be utilized to satisfy differing user objectives. When option (a) is utilized for all arcs the network is considered fully constrained. The more constrained the network, the more likely the resultant solution will be infeasible.

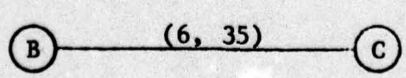
In the description thus far, reference has been made to time-to-train and weekly class size for phase arcs; input rates for input arcs; and PTR rates for output arcs in the context that, for each arc, these values remain constant from week to week. Also, the implication has been that the flow solution represents a constant uniform rate which is repeated each and every week. It is this repetitive use of the network flow solution from which the term Dynamic Network Flow is derived.

As long as the model is of the Dynamic Form this constancy of arc parameters is required and, in the training process being modeled, represents a serious restriction on the model's applicability. This restriction can be removed by expanding the network to form what is termed a Static Network Model which is described next.

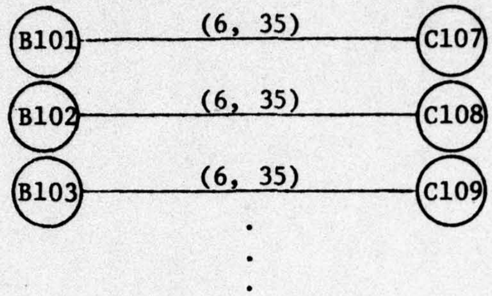
3.1.2 The Static Network

The static interpretation of a network considers each arc as having only a single use. The multiple use implied by the dynamic interpretation is accommodated by replicating the network once for each implied use. Thus, to model the flow of students entering the training system over a period of one year (50 training weeks), the network diagrammed in Figure 3.1 would be replicated 50 times, one replication for each training week.

For examp e, assume that the Primary Phase has a length of 6 weeks and a weekly maximum class size of 35 students. Coding this information along the arc, the Primary Phase arc as diagrammed in Figure 3.1 becomes:



If the node identifier scheme is expanded to include a three digit number where the first indicates the year and the other two the week a class starts, then the sequence of Primary classes can be represented as:



In the above, the first arc represents the Primary class of up to 35 students which begins training the first week of the first year modeled, spends 6 weeks under training, and is available for assignment to the next phase of training the seventh week of the first year modeled. The second and third classes are similarly represented. Using this scheme, the diagram in Figure 3.1 can be expanded to represent the training process for whatever time period necessary.

Expanding a network in this manner facilitates the handling of variable cost and capacity parameters and allows the modeling of student pools. Since each phase arc is now represented by a set of class arcs, each class arc can be assigned a time-to-train value and a capacity value which most nearly represents the real world values for the particular class represented. Thus, variations in these values throughout the period modeled can be accommodated.

Student pools were defined as those students available to start a particular class for which there is no room and, as a consequence, must be held over for a class beginning one or more weeks later. Such pools can be represented by arcs connecting nodes having the same letter code and successively higher numeric values. By convention, such arcs are assigned virtually unlimited capacity (9999) and a cost similar to the longest path through the network ($\sim$50 weeks). Thus, student pools can be of whatever size required but will be avoided, if possible, by the flow insertion algorithm due to their excessively high cost.

Based upon the above, a segment of the Primary Phase may be diagrammed as shown in Figure 3.2. In Figure 3.2 both class length and class size have been varied and the student pool arcs have been included.

3.2 Calculation of Arc Parameter Values

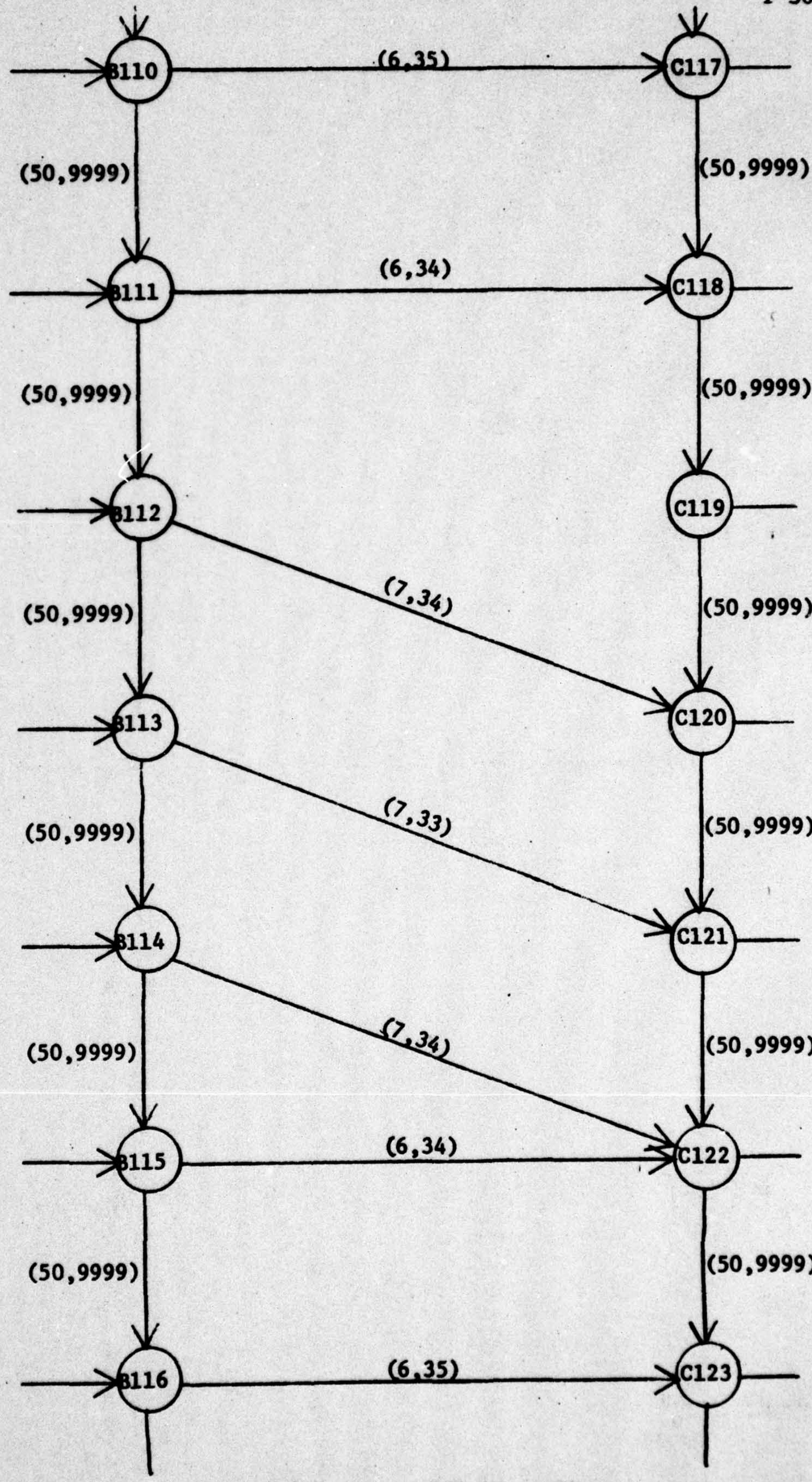
The selection of a methodology for computing arc parameter values requires that certain assumptions, approximations, and rationalizations be made regarding the training processes being modeled. The decision processes involved in the selection are guided by a desire to limit the level of detail to that which adequately represents the training environment but which, at the same time, does not unnecessarily complicate the representation. The establishment of a particular level of detail as just adequate is somewhat subjective and raises the question of "What price precision?" One can very easily be mislead in the area of precision and include a level of detail that implies a precision greater than that inherent in the model. In the sequel, a methodology is given which is believed to be adequate; however, this description should not be construed as to imply that this is THE methodology, but simply, that this is the one utilized for this report.

3.2.1 Calculation of Cost Parameters

The cost parameter has been defined to be the time-to-train in weeks for arcs representing training, zero for input and output arcs, and arbitrarily high for student pool arcs. The subject addressed here is the calculation of the cost parameter for individual class training arcs.

If the length of each class for a particular phase of training were the same, the assignment process would be simple, i.e., the value assigned would be the planned annual average time-to-train. Such may be the case for phases that are strictly academic but, for phases that involve flight training, many variables come into play which cause seasonal variations in the time-to-train.

It can be noted from historical data that for a phase involving flight training, winter classes are, in general, longer than summer classes.



Expanded Segment of Primary Phase

Figure 3.2

It can also be noted that available daylight flyable hours (daylight hours times weather factor) are less in the winter than in the summer. Since most phases are predominately daylight flight training, the inverse relationship between available daylight flyable hours and class length is taken to be a cause and effect relationship. The assumption that the total number of required daylight flyable hours remains constant for the completion of each class without regard to the time of the year is sufficient to account for the fact that winter classes are longer than summer classes.

In the discussion below, the running variables i and j represent the day and week, respectively, of the fiscal year. Assuming that (a) each year of interest is the same, i.e., composed of exactly 52 weeks (an approximation of little consequence) and (b) the planning factors hold from year to year, these running variables take on the values:

$$i = 1, 2, \ldots, 364$$

$$j = 1, 2, \ldots, 52$$

The stepping of the running variables is defined to be:

$$[i+1] \rightarrow [(i \bmod 364) + 1]$$

$$[j+1] \rightarrow [(j \bmod 52) + 1]$$

and the requisite planning factors are:

L Annual average class length in weeks

H_i Daylight hours on day i*

W_i Weather factor on day i*

D_i Work day factor ($1 \rightarrow$ workday, $0 \rightarrow$ non-workday)

---

*These planning factors are usually given as monthly averages. The value for day i is the same as the value for the month within which day i is contained.

From the above the annual average flyable hours per training week, F, may be calculated based on 50 training weeks per year (two weeks off at Christmas):

$$F = \frac{\sum_{i=1}^{364} D_i W_i H_i}{50} .$$

Therefore, the average flyable hours available to the average class of length L is $F \times L$ and it is this value that is to be utilized to determine the length of a particular class.

Identifying classes by the week they begin, the length of class J, L_j, is defined to be:

$$L_j = n + \frac{FL - F_{nj}}{F_{(n+1)j} - F_{nj}}$$

with F_{nj} respresenting the flyable hours available during an n-week period beginning week j:

$$F_{nj} = \sum_{k=j}^{j+n-1} \sum_{i \epsilon k} D_i W_i H_i {}^{*}$$

and the positive integer n chosen so that:

$$F_{nj} \leq FL < F_{(n+1)j} {}^{**} .$$

The assignment of the cost parameter to the arc representing class j is then L_j rounded to an integer.

---

*$i \epsilon k$ implies that day i is part of week k.

**$F_{(n+1)j}$ refers to the next week containing at least one workday.

3.2.2 Calculation of Capacity Parameters

The initial step in assigning the capacity parameter to the individual arcs is to determine the annual aircraft utilization that can be expected. In most cases to date, the choice was to exercise a locally developed Aircraft Utilization Model for the particular training site. This model employs a Monte Carlo simulation technique in order to comprehend the numerous circumstances which affect the expected annual aircraft utilization. In a particular application, the appropriate version of the model is defined by:

a. the specified flight training base,

b. the real or projected operating circumstances, and

c. the mix and inventories of the training aircraft at the base.

Most versions of the Aircraft Utilization Model comprehend only the daylight portion of flight operations. This introduces no significant error so long as the night time portion of the training syllabus is small compared to the daylight portion of the syllabus. The underlying assumption is that the night flying requirements can easily keep pace with the daylight operations. The resultant predicted aircraft utilization by phase must then be multiplied by the ratio of total phase syllabus time to the daylight phase syllabus time. This number is divided by the number of training weeks in a year (50) to get the average flight hours generated in a week for each phase.

The average flight hours per week by phase is divided by the phase flight time required per pipeline graduate to get the average weekly phase graduates. The phase flight time required per pipeline graduate includes all overhead flight time for that particular phase plus the attrition for all subsequent phases in the pipeline.

To state the process symbolically, the following definitions are used.

T = Total Annual Daylight Flight Hours

R = Ratio of Total Syllabus Flight Hours to Daylight Flying Hours

50 = Training Weeks per Year

A = Total Phase Flight Time per Pipeline Graduate

G = Average Weekly Phase Graduates

Then:

$$G = TR/50A$$

Alternatively, TR could be replaced by a planning factor for the Annual Aircraft Utilization. This is sometimes necessary in hypothetical planning situations where not enough is known about the details of the operating circumstances to justify the use of the Aircraft Utilization Model. When this is not the case, the use of the Aircraft Utilization Model is preferred as it is known that the aircraft utilization is a function of the aircraft inventories.

Now, to compute the actual arc capacity for each arc, the ratio of L/L_j is used. The arc capacity is then:

$$G_j = LG/L_j \ .$$

The matter of attrition was accounted for in the following way. Consider a three phase training pipeline where the attrition X_1 takes place in the first phase, P_1 . Similarly, X_2 in P_2 and X_3 in P_3 . Now the planning factor "Aircraft Hours per Student" is usually defined as the average total aircraft hours required for phase completion of a student including all prorated extra-time and ancillary hours. This includes those hours devoted to students who attrite in the phase. The value of this planning factor is symbolized by H_k where k is the phase number.

The hours required for a pipeline graduate for students in Phase k is A_k computed as follows:

$$A_3 = H_3$$

$$A_2 = (1+X_3)H_2$$

$$A_1 = (1+X_2)(1+X_3)H_1 \ .$$

This increase in the number of hours required in phase for a pipeline graduate has the effect of reducing the capacity in the arc representing the phase in the network. Moreover, the number of students scheduled to enter the pipeline will be reduced by a factor of $[1/(1+X_1)(1+X_2)(1+X_3)]$ in this example.

The method for accounting for attrites used here is to deflate all arc capacities to a level where every student flowing through the system represents a pipeline graduate. Once a flow solution is obtained, then the arc flows must be inflated to determine the actual number of students entering a phase. For instance, the actual number of P_2 graduates would be the number of students in the flow solution times $(1+X_3)$.

This method of accounting for attrition lacks theoretical rigor but from a pragmatic perspective it seems to work reasonably well. Research in network flow theory has produced some algorithms for flows with gains and losses. An example is Reference [23]. There are a number of practical disadvantages in adding this layer of sophistication, some of which are:

a. more elaborate processing,

b. more complex network structures, and

c. difficulty in maintaining integer flow values.

3.3 The Five-Year Network Representation

The expanded network utilized by the DSFM can be very large. For example, the expanded version of the network diagrammed in Figure 3.1 requires on the order of 450 nodes, 400 class arcs, 450 student pool arcs, 50 input arcs, and 150 output arcs for each year modeled. In terms of network processing, a one-year network, some 450 nodes and 1,050 arcs, would be considered large and a five-year network, some 2,250 nodes and 5,250 arcs, would be so large as to exceed the capabilities of many of the existing processing systems and techniques.

The practical limit of the size of a network is governed by two requirements, memory space and solution time. The required memory space

is a direct function of network size, i.e., twice as large requires twice as much computer memory. Solution time, however, is approximately a function of the square of network size, i.e., twice as large requires about four times as much computer time to generate a solution. Thus, a solution cost ratio of about 25 to 1 exists between a five-year model versus a one-year model.

The assumptions made in constructing the expanded network (Section 3.2.1), that each year modeled is the same and that the planning factors affecting class length hold from year to year, result in each year of the network being a replica, as far as form, of the first year modeled. The only year-to-year differences that can exist in the expanded network are (a) in the capacity parameter values and (b) having generated a solution, in the value of the flow inserted.

By taking advantage of this year-to-year similarity of the network, it is possible to condense, in terms of number of nodes and arcs, a five-year network into a one-year network. This is accomplished by including in each arc five flow and capacity entries, one set for each year modeled, and appropriately modifying the flow insertion algorithm (a) to recognize arcs that span the fiscal year boundary and (b) to allow for up to five uses for each path located. The necessary modifications to the arc and node tables allow the five-year network to require less than twice the computer memory space and solution time than that required for a one-year model.

3.4 Network Preload

In the discussion thus far, a methodology has been described for constructing a network which models the flow of students from entry into flight training through designation as Naval Aviators. The flight training

process is about a year in length and, as such, about one year's input of students are in the system at any instant in time. This "current state" of the system is accounted for by preloading the network with a flow representing the students in the system at the beginning of the period of interest.

For example, refer to Figure 3.1 and assume that the period of interest begins with the 16th week of the current fiscal year and continues through the following four fiscal years. Also, assume that the length of the Primary Phase for the class beginning the 16th week is nine* weeks, that during the 15th week there are 133 primary students on board, and that 10 of those students graduate Primary training at the end of the 15th week.

In modeling the current state for the Primary Phase, the network is constructed according to the methodology given in Sections 3.2 and 3.3. Since the period of interest begins with the 16th week the capacity entries for the first year of the arcs (BC) beginning weeks one through 15 are set to zero. With a class length of nine weeks, the arc beginning week 16 lasts through week 24 and connects to node C25 (the next phase of training starts on week 25). At this point in the discussion, nodes C16 through C24 have arcs leading from them with positive capacity in the first year's entries but do not have any arcs leading to them with positive capacity in the first year. It is to these nodes that the current onboard primary students enter the model.

To preload the Primary Phase, a new source node, the preload source, is created and preload arcs connecting the preload source to each of the nodes C16 through C24 are constructed. The first year's capacity field in each of these nine arcs is assigned the value representing the number of students graduating Primary Phase during the first nine weeks of interest (a total capacity of 133). For instance, the arc connecting the preload source and node C16 has a capacity of 10 students, the number graduating week 15. The other four years' capacity entries are set to zero in all preload arcs.

---

*Includes two weeks leave in transit.

Preload arcs are constructed for each of the other phases of training in a similar manner utilizing the same preload source node. This additional network construction having been made, the next step is to insert the preload flow.

The preload flow is inserted by restricting the flow insertion algorithm to that flow originating at the preload source. After that source is exhausted the algorithm is then allowed to insert flow originating from the normal input source node. This two-step process insures that flow representing the initial student onboard load will be inserted prior to that representing new entrants into the system.

3.5 Network Postload

Just as there are about a year's input of students in the system at the beginning of the time period of interest so are there at the end of the time period of interest. The modeling of these onboard students at the end of the time period of interest is termed network postload.

Network postload may be handled in one of two methods. One method is analogous to that described above for preload. The difference being that those classes beginning during the time period of interest but which end after the time period of interest would be connected to a postload destination, their cumulative capacity would be set to reflect the desired onboard load at the end of the time period of interest, and an additional pass of the flow insertion algorithm utilizing the postload destination in lieu of the normal destination would be invoked.

A simpler method, that which was utilized by the current model, is to model beyond the time period of interest by at least the length of the longest path from input to destination. Extending the time period allows the inputs up to the end of the time period of interest to reach the destination within the time period modeled. Thus, with the total time-to-train on the order of 50 weeks, the five-year model is useful for the remainder of the fiscal year containing the beginning of the time period of interest and the following three fiscal years.

4. Scenarios

Two scenarios were composed as vehicles for demonstrating the capabilities of the DSFM. These scenarios were drawn from fragmentary information by the research team and do not necessarily reflect the intentions of the Naval Air Training Command at any time. Both scenarios involve a transition period of base closures, squadron decommissionings, new syllabi and aircraft and squadron movement.

4.1 Scenario No. 1

a. Consolidate helo training under the Army at Ft. Rucker.

b. Decommission:

6/76	VT-5 at Saufley (Training Squadron)
10/76	VT-1 at Saufley (Training Squadron)
10/76	NAS at Saufley (Training Base)
2/77	VT-27 at Corpus (Training Squadron)
3/77	HT-8 at Whiting (Training Squadron)
5/77	HT-18 at Whiting (Training Squadron)
9/77	TRAWING FOUR at Corpus (Training Wing)
9/77	NAS at Corpus (Training Base)
12/77	VT-9 at Meridian (Training Squadron)
12/77	VT-19 at Meridian (Training Squadron)
4/78	VT-7 at Meridian (Training Squadron)
4/78	TRAWING ONE at Meridian (Training Wing)
4/78	NAS at Meridian (Training Base)

c. Upon decommissioning the squadrons at Meridian, transfer their aircraft to Chase and Kingsville.

d. Implement the Navy Integrated Flight Training System (NIFTS). NIFTS is essentially a new set of syllabi with new phase names and some new types of aircraft.

e. Introduce the T-34C and T-44A according the following schedule:

T-34C	J	F	M	A	M	J	J	A	S	O	N	D
1976									3	6	10	15
1977	21	27	33	40	54	61	68	75	82	89	96	99
1978	102	105	108	111	114	117	120	123	126	129	131	134
T-44A												
1977				1	3	4	6	7	9	10	12	13
1978	15	17	19	21	23	25	27	29	31	33	35	37

f. The following is the PTR schedule.

	JET	PROP	HELO	TOTAL
FY76	522	405	508	1,435
TQ77	121	103	106	330
FY77	555	329	506	1,390
FY78	510	299	503	1,312
FY79	554	324	484	1,362
FY80	569	326	585	1,380

Figure 4.1 delineates the time phasing of this scenario. Where the tapered edge of the training phase strips is pointing to the right, the beginning indicates the date the last student enters the training phase and the end indicates the date of the last graduate. If the tapered edge points to the left, the beginning indicates the date the first student enters the training phase and the end is the date of the first graduate.

4.2 Scenario No. 2

a. Retain helo training.

b. Decommission NAS Saufley, VT-1 and VT-5 on 30 September 1976. No other base closures or squadron decommissioning.

c. Start NIFTS on 31 August 1976.

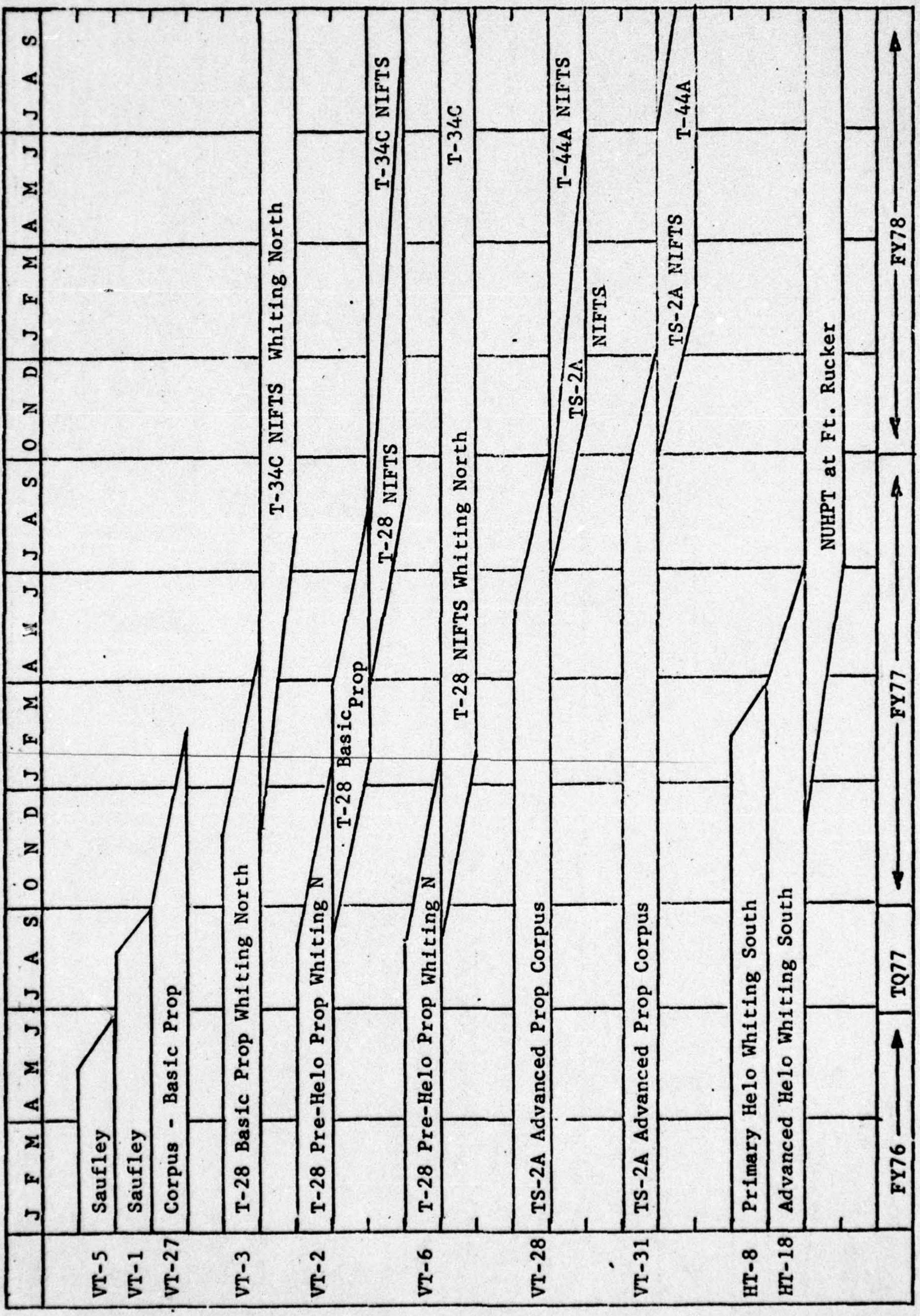
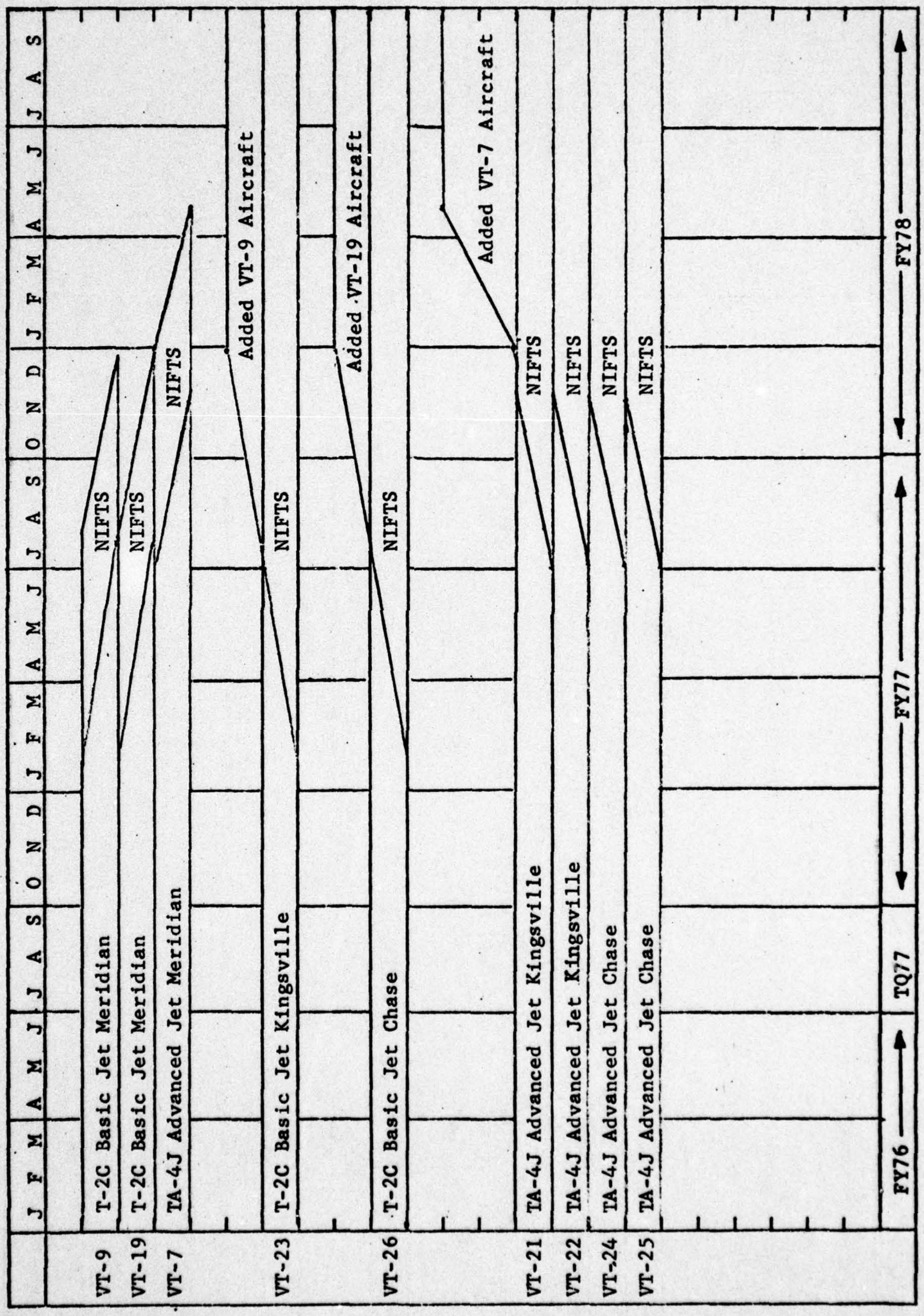

J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
VT-5
VT-1
VT-27
VT-3
VT-2
VT-6
VT-28
VT-31
HT-8
HT-18
Saufley
Saufley
Corpus - Basic Prop
T-28 Basic Prop Whiting North
T-34C NIFTS Whiting North
T-28 Pre-Helo Prop Whiting N
T-28 Basic Prop
T-28 NIFTS
T-34C NIFTS
T-28 Pre-Helo Prop Whiting N
T-28 NIFTS Whiting North
T-34C
TS-2A Advanced Prop Corpus
TS-2A NIFTS
T-44A NIFTS
TS-2A Advanced Prop Corpus
TS-2A NIFTS
T-44A
Primary Helo Whiting South
Advanced Helo Whiting South
NUHPT at Ft. Rucker
FY76
TQ77
FY77
FY78

Figure 4.1a



J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
VT-9
T-2C Basic Jet Meridian
VT-19
T-2C Basic Jet Meridian
VT-7
TA-4J Advanced Jet Meridian
VT-23
T-2C Basic Jet Kingsville
VT-26
T-2C Basic Jet Chase
VT-21
TA-4J Advanced Jet Kingsville
VT-22
TA-4J Advanced Jet Kingsville
VT-24
TA-4J Advanced Jet Chase
VT-25
TA-4J Advanced Jet Chase
NIFTS
Added VT-9 Aircraft
Added VT-19 Aircraft
Added VT-7 Aircraft
FY76
TQ77
FY77
FY78

Figure 4.1b

d. Introduce T-34C into VT-3, 2, 6 and 27 in that order. Introduce T-44A into VT-28 and 31 in that order. Fill each squadron before assigning new aircraft to the next squadron. The delivery schedules are as follows:

T-34C	J	F	M	A	M	J	J	A	S	O	N	D
1976												16
1977	22	28	28	34	40	46	52	58	64	70	77	84
1978	91	98	106	114	126	138	150	162	174	186	198	210
1979	212	208	200	200	200	200	200	200	200	200	200	200
T-44A												
1977				4	6	8	10	12	14	15	16	17
1978	19	21	23	25	27	29	31	33	35	37	39	41
1979	43	45	47	49	51	53	55	57	59	61	61	61

e. Change the T-28's to a total inventory as follows:

1976							156	156	156	186	206	224
1977	224	228	199	194	191	188	176	171	166	161	156	151
1978	144	139	132	125	114	103	92	81	70	52	25	11

f. Program for level monthly output of students by pipeline.

g. Same PTRs as for Scenario No. 1.

h. The 2F130 Flight Simulator becomes available at Whiting beginning FY79. (This reduces the number of T-34C syllabus flight hours required.)

Figure 4.2 delineates the time phasing of this scenario.

5. Input

5.1 Student Input Arcs

An OPNAV NOTE 1542, usually issued in the spring, gives the weekly input schedule of flight students for the coming fiscal year. Beyond this time, some assumptions have to be made with respect to the weekly inputs.

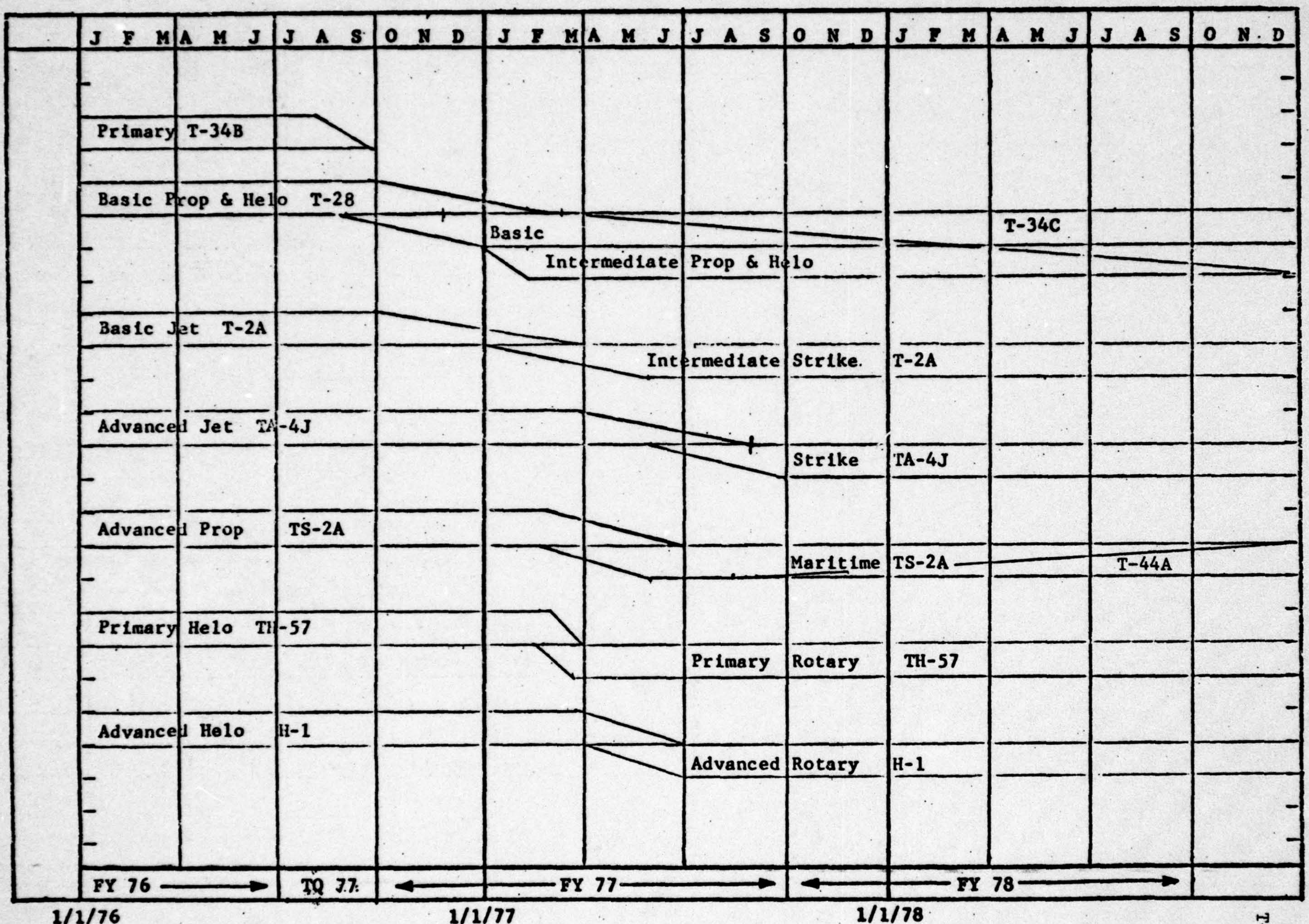


Figure 4.2

T-362

The scheduled students then become the capacities, appropriately decremented for pipeline attrition, in the weekly input arcs of the network. These arcs have a zero time length with the initial node at the network source and the terminal node at the actual week of student entry into flight training. A useful exercise for the DSFM is to place an infinite capacity on all weekly input arcs and use the DSFM to compute an optimal flight student input schedule for the next year or more.

The onboard student load is needed to start up the DSFM. Fortunately for the scenario exercises addressed herein, the Chief of Naval Air Training originated a message calling for one-time report to include the estimated weeks to go in phase for all students on board as of the close of business 5 January 1976. Although the message was motivated by other purposes, the response provided an excellent starting point for the DSFM. The onboard student load is reported routinely and is always available. In the absence of the "weeks to go" data, one could assume that the student load was uniformly distributed over the weeks in the average phase length. The reported data as of 5 January 1976, however, was not uniformaly distributed. Similar to the weekly input student schedule, the distribution of the onboard load provides the capacities for the weekly phase load arcs. For example, all students that have three weeks to go in phase would be the capacity (decremented for attrition) in a three-week arc connected to the first terminal node for the phase.

5.2. Training Phase Arcs

The computations for determining the time and capacity parameters for these arcs have been described earlier in Section 3. While these computations are straightforward, the translation of a scenario into the numbers required for the computations may not be. Particularly, if the scenario involves a transition period. To properly make the translation not only requires a working knowledge of the DSFM but, more importantly, a fine intuitive sense for the significant operating circumstances affecting flight hour generation in a planning and execution situation. Checking, cross-checking and rechecking with all elements of the staff should be a necessary part of any translation.

Figure 5.1 is a sample of the work sheets used in setting up the DSFM. These work sheets are produced by the computer after it has structured the arcs and nodes of the desired network. The example is for the Primary Phase at Saufley. Following the phase-place column are two columns: a "Q" and "A" column. These represent the initial and terminal nodes of the arc representing the Primary class which starts on the week designated by the "Q" node. For instance, the first line states that the first class starts at Q01, the first week of the fiscal year,* and is ready to start the next phase of training on week A10, a difference of nine weeks. Two of these weeks are allowed for leave and transit. The next five columns are blank for inserting arc capacities for up to five years. The final column is the phase duration in weeks and is automatically calculated.

At the end of the "Q" and "A" column, there are some "S" and "A" columns. These arcs are provided for the onboard student load that have varying "weeks to go" before completing the phase.

5.3 PTR Arcs

PTR arcs have zero time length. PTRs are by type training: jet, prop or helo. If only the annual PTR's are of concern, then only one PTR arc by type is needed for each year in the planning period. The capacity of the arc is the type PTR undecremented for any attrition. If, however, a particular distribution of graduates over the months is desired, then a PTR arc is needed for each month where the sum of the monthly capacities in a year are equal to the annual PTR. Similarly, it can be done for weeks. A useful exercise for the DSFM is to place an infinite PTR on these arcs and let the DSFM determine the maximum output of the training system with respect to the capacity for generating flight hours.

---

*This is set up for the new fiscal years starting 1 October. The transition quarter is counted as an extension to FY76.

-- NETWORK DATA SHEET --			1976	1977	1978	1979	1980	
PRIMARY-SAUFLEY	Q01	A10	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q02	A11	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q03	A12	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q04	A15	----	----	----	----	----	7
PRIMARY-SAJFLEY	Q05	A15	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q06	A18	----	----	----	----	----	8
PRIMARY-SAUFLEY	Q07	A19	----	----	----	----	----	8
PRIMARY-SAUFLEY	Q08	A20	----	----	----	----	----	8
PRIMARY-SAUFLEY	Q09	A21	----	----	----	----	----	8
PRIMARY-SAUFLEY	Q10	A22	----	----	----	----	----	8
PRIMARY-SAUFLEY	Q11	A23	----	----	----	----	----	8
PRIMARY-SAUFLEY	Q12	A24	----	----	----	----	----	8
PRIMARY-SAJFLEY	Q15	A25	----	----	----	----	----	8
PRIMARY-SAUFLEY	Q16	A25	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q17	A26	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q18	A27	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q19	A28	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q20	A29	----	----	----	----	----	7
PRIMARY-SAUFLEY	Q21	A29	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q22	A30	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q23	A31	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q24	A32	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q25	A33	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q26	A34	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q27	A35	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q28	A36	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q29	A37	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q30	A38	----	----	----	----	----	6
PRIMARY-SAUFLEY	Q31	A38	----	----	----	----	----	5

Figure 5.1a

-- NETWORK DATA SHEET --			1976	1977	1978	1979	1980	
PRIMARY-SAUFLEY	Q32	A39	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q33	A40	____	____	____	____	____	5
PRIMARY-SAJFLEY	Q34	A41	____	____	____	____	____	6
PRIMARY-SAUFLEY	Q35	A42	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q36	A43	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q37	A44	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q38	A45	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q39	A46	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q40	A47	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q41	A48	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q42	A49	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q43	A50	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q44	A51	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q45	A52	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q46	A01	____	____	____	____	____	5
PRIMARY-SAUFLEY	Q47	A03	____	____	____	____	____	6
PRIMARY-SAUFLEY	Q48	A04	____	____	____	____	____	6
PRIMARY-SAUFLEY	Q49	A05	____	____	____	____	____	6
PRIMARY-SAUFLEY	Q50	A06	____	____	____	____	____	6
PRIMARY-SAUFLEY	Q51	A07	____	____	____	____	____	6
PRIMARY-SAUFLEY	Q52	A08	____	____	____	____	____	6
PRIMARY-SAUFLEY	S00	A16	____	____	____	____	____	1
PRIMARY-SAUFLEY	S00	A17	____	____	____	____	____	2
PRIMARY-SAJFLEY	S00	A18	____	____	____	____	____	3
PRIMARY-SAUFLEY	S00	A19	____	____	____	____	____	4
PRIMARY-SAUFLEY	S00	A20	____	____	____	____	____	5
PRIMARY-SAUFLEY	S00	A21	____	____	____	____	____	6
PRIMARY-SAUFLEY	S00	A22	____	____	____	____	____	7

Figure 5.1b

6. Results and Conclusions

6.1 Output

Figure 6.1 is an example of the arc data output after the DSFM has reached a solution. The first two columns, FROM-TO, are the coded nodes for the arc addressed. Arcs coded B to C in the example are Advanced Jet at Chase. The S to C arcs are the onboard load arcs. A to D arcs are Basic Jet at Kingsville. The column NEXT-FROM and NEXT-TO contain programmatic data. The five columns under CIJ contain the capacities for the years considered; the first column being FY76. In the example for the B to C arcs, the last non-zero entry is at B31 to C48. This marks the time when there can be no more graduates from the old syllabus and the shift is being made to the NIFTS syllabus. The XIJ columns contain the individual arc flows contained in the solution. The TIJ column lists the time length in weeks of each arc. The last two columns contain more programmatic information.

Figure 6.2 is the Weekly Schedule for Advanced Jet at Chase. Week 01 is the first week in October. Weeks 13 and 14 are omitted for the Christmas Holiday. The three columns under the year headings contain the number of students entering the phase, the number graduating and the onboard load. The number graduating at the end of the week are still counted as part of the onboard load and subtracted from the onboard load for the following week. It may be worth repeating here that all of the output numbers representing students are decremented for any pipeline attrition in the succeeding phases. The example here, however, is for Advanced Jet which has no succeeding phase. The phasing out of Advanced Jet can readily be seen in this printout; i.e., week for last student IN and the last OUT.

Figure 6.3 is a page from the listing of all the holdover or pooled students by week, phase and location. Totals are also given for each year.

Figure 6.4 is a page from the listing containing all unused capacity in terms of phase graduates for each arc in the network.

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THE GEORGE WASHINGTON UNIVERSITY

CSM#1 S3

ARC LIST

05/07/76

FROM	TO	NEXT-FROM	NEXT-TO	CIJ					XIJ					TIJ	PHASE	INDEX
B20	C39			6	6	0	0	0	4	5	0	0	0	19	3	601
B21	C40			6	6	0	0	0	3	0	0	0	0	19	3	602
B22	C41			6	6	0	0	0	2	4	0	0	0	19	3	603
B23	C42		605	6	6	0	0	0	1	4	0	0	0	19	3	604
B24	C42			6	6	0	0	0	0	0	0	0	0	18	3	605
B25	C43			6	6	0	0	0	6	4	0	0	0	18	3	606
B26	C44			6	6	0	0	0	4	4	0	0	0	18	3	607
B27	C45			6	6	0	0	0	1	0	0	0	0	18	3	608
B28	C46		610	6	6	0	0	0	4	0	0	0	0	18	3	609
B29	C46			7	7	0	0	0	1	0	0	0	0	17	3	610
B30	C47			7	7	0	0	0	1	0	0	0	0	17	3	611
B31	C48			7	7	0	0	0	3	0	0	0	0	17	3	612
B32	C49			7	0	0	0	0	4	0	0	0	0	17	3	613
B33	C50			7	0	0	0	0	2	0	0	0	0	17	3	614
B34	C51			7	0	0	0	0	7	0	0	0	0	17	3	615
B35	C52			7	0	0	0	0	3	0	0	0	0	17	3	616
B36	C01			7	0	0	0	0	4	0	0	0	0	17	3	617
B37	C02			7	0	0	0	0	7	0	0	0	0	17	3	618
B38	C04			6	0	0	0	0	6	0	0	0	0	18	3	619
B39	C05			6	0	0	0	0	6	0	0	0	0	18	3	620
B40	C06			6	0	0	0	0	5	0	0	0	0	18	3	621
B41	C07			6	0	0	0	0	5	0	0	0	0	18	3	622
B42	C09			6	0	0	0	0	5	0	0	0	0	19	3	623
B43	C11			6	0	0	0	0	6	0	0	0	0	20	3	624
B44	C12			6	0	0	0	0	6	0	0	0	0	20	3	625
B45	C16		634	5	0	0	0	0	5	0	0	0	0	23	3	626
B46	C18		636	5	0	0	0	0	5	0	0	0	0	24	3	627
B47	C19		637	5	0	0	0	0	5	0	0	0	0	24	3	628
B48	C20		638	5	0	0	0	0	5	0	0	0	0	24	3	629
B49	C22		640	5	0	0	0	0	5	0	0	0	0	25	3	630
B50	C23		641	5	0	0	0	0	0	0	0	0	0	25	3	631
B51	C24		642	5	0	0	0	0	5	0	0	0	0	25	3	632
B52	C25		643	5	0	0	0	0	5	0	0	0	0	25	3	633
S00	C16	635		1	0	0	0	0	1	0	0	0	0	1	3	634
S00	C17	636		2	0	0	0	0	2	0	0	0	0	2	3	635
S00	C18	637		1	0	0	0	0	1	0	0	0	0	3	3	636
S00	C19	638		1	0	0	0	0	1	0	0	0	0	4	3	637
S00	C20	639		7	0	0	0	0	7	0	0	0	0	5	3	638
S00	C21	640		3	0	0	0	0	3	0	0	0	0	6	3	639
S00	C22	641		5	0	0	0	0	5	0	0	0	0	7	3	640
S00	C23	642		1	0	0	0	0	1	0	0	0	0	8	3	641
S00	C24	643		3	0	0	0	0	3	0	0	0	0	9	3	642
S00	C25	644		5	0	0	0	0	5	0	0	0	0	10	3	643
S00	C26	645		2	0	0	0	0	2	0	0	0	0	11	3	644
S00	C27	646		7	0	0	0	0	7	0	0	0	0	12	3	645
S00	C28	647		2	0	0	0	0	2	0	0	0	0	13	3	646
S00	C29	648		4	0	0	0	0	4	0	0	0	0	14	3	647
S00	C30	649		4	0	0	0	0	4	0	0	0	0	15	3	648
S00	C31	650		3	0	0	0	0	3	0	0	0	0	16	3	649
S00	C32	651		3	0	0	0	0	3	0	0	0	0	17	3	650

Figure 6.1

PROGRAM IN LOGISTICS
INSTITUTE FOR MANAGEMENT SCIENCE AND ENGINEERING
THE GEORGE WASHINGTON UNIVERSITY

CSM#1 S3 WEEKLY SCHEDULE FOR ADVANCED JET-CHASE 05/07/76

	<-	1976	->	<-	1977	->	<-	1978	->	<-	1979	->	<-	1930	->
WEEK	IN	OUT	LOAD	IN	OUT	LOAD	IN	OUT	LOAD	IN	OUT	LOAD	IN	OUT	LOAD
01	0	0	0	5	7	86	0	0	0	0	0	0	0	0	0
02	0	0	0	5	0	84	0	0	0	0	0	0	0	0	0
03	0	0	0	4	6	88	0	0	0	0	0	0	0	0	0
04	0	0	0	5	6	87	0	0	0	0	0	0	0	0	0
05	0	0	0	5	5	86	0	0	0	0	0	0	0	0	0
06	0	0	0	5	5	86	0	0	0	0	0	0	0	0	0
07	0	0	0	5	0	86	0	0	0	0	0	0	0	0	0
08	0	0	0	0	5	86	0	0	0	0	0	0	0	0	0
09	0	0	0	5	0	86	0	0	0	0	0	0	0	0	0
10	0	0	0	5	6	91	0	0	0	0	0	0	0	0	0
11	0	0	0	1	6	86	0	0	0	0	0	0	0	0	0
12	0	0	0	5	0	85	0	0	0	0	0	0	0	0	0
15	73	1	73	0	5	85	0	0	0	0	0	0	0	0	0
16	0	2	72	5	0	85	0	0	0	0	0	0	0	0	0
17	0	1	70	5	5	90	0	0	0	0	0	0	0	0	0
18	0	1	69	5	5	90	0	0	0	0	0	0	0	0	0
19	0	7	68	0	5	85	0	0	0	0	0	0	0	0	0
20	4	3	65	5	0	85	0	0	0	0	0	0	0	0	0
21	3	5	65	0	5	85	0	0	0	0	0	0	0	0	0
22	2	1	62	4	0	84	0	0	0	0	0	0	0	0	0
23	1	3	62	4	5	88	0	0	0	0	0	0	0	0	0
24	0	5	59	0	5	83	0	0	0	0	0	0	0	0	0
25	6	2	60	4	5	82	0	0	0	0	0	0	0	0	0
26	4	7	62	4	5	81	0	0	0	0	0	0	0	0	0
27	1	2	56	0	4	76	0	0	0	0	0	0	0	0	0
28	4	4	58	0	5	72	0	0	0	0	0	0	0	0	0
29	1	4	55	0	5	67	0	0	0	0	0	0	0	0	0
30	1	3	52	0	5	62	0	0	0	0	0	0	0	0	0
31	3	3	52	0	5	57	0	0	0	0	0	0	0	0	0
32	4	6	53	0	5	52	0	0	0	0	0	0	0	0	0
33	2	6	49	0	5	47	0	0	0	0	0	0	0	0	0
34	7	6	50	0	1	42	0	0	0	0	0	0	0	0	0
35	3	1	47	0	5	41	0	0	0	0	0	0	0	0	0
36	4	0	50	0	10	36	0	0	0	0	0	0	0	0	0
37	7	0	57	0	5	26	0	0	0	0	0	0	0	0	0
38	6	4	63	0	5	21	0	0	0	0	0	0	0	0	0
39	6	3	65	0	0	16	0	0	0	0	0	0	0	0	0
40	5	2	67	0	4	16	0	0	0	0	0	0	0	0	0
41	5	1	70	0	4	12	0	0	0	0	0	0	0	0	0
42	5	6	74	0	4	8	0	0	0	0	0	0	0	0	0
43	6	4	74	0	4	4	0	0	0	0	0	0	0	0	0
44	6	1	76	0	0	0	0	0	0	0	0	0	0	0	0
45	5	5	80	0	0	0	0	0	0	0	0	0	0	0	0
46	5	1	80	0	0	0	0	0	0	0	0	0	0	0	0
47	5	3	84	0	0	0	0	0	0	0	0	0	0	0	0
48	5	4	86	0	0	0	0	0	0	0	0	0	0	0	0
49	5	2	87	0	0	0	0	0	0	0	0	0	0	0	0
50	0	7	85	0	0	0	0	0	0	0	0	0	0	0	0
51	5	3	83	0	0	0	0	0	0	0	0	0	0	0	0
52	5	4	85	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6.2

PROGRAM IN LOGISTICS
INSTITUTE FOR MANAGEMENT SCIENCE AND ENGINEERING
THE GEORGE WASHINGTON UNIVERSITY

CSN#1 53 SCHEDULE OF HOLDOVERS AFTER PHASE COMPLETION 05/07/76

	--PRIMARY-SAUFLEY--					--BASIC JET-CHASE--					BASIC JET-KINGSVILLE					BASIC JET-MERIDIAN					BASIC JET-PENSACOLA				
WEEK	YR1	YR2	YR3	YR4	YR5	YR1	YR2	YR3	YR4	YR5	YR1	YR2	YR3	YR4	YR5	YR1	YR2	YR3	YR4	YR5	YR1	YR2	YR3	YR4	YR5
01-02	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02-03	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
05-06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06-07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07-08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08-09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10-11	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
12-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-18	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18-19	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19-20	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-21	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-22	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-23	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-26	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0
26-27	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
27-28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29-30	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
30-31	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
31-32	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34-35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35-36	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0
36-37	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	9	0	0	0	0	0	0	0	0	0
37-38	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	11	0	0	0	0	0	0	0	0	0
38-39	20	0	0	0	0	1	0	0	0	0	9	0	0	0	0	10	0	0	0	0	0	0	0	0	0
39-40	11	0	0	0	0	0	0	0	0	0	12	0	0	0	0	13	0	0	0	0	1	0	0	0	0
40-41	4	0	0	0	0	0	0	0	0	0	15	0	0	0	0	16	0	0	0	0	3	0	0	0	0
41-42	3	0	0	0	0	0	0	0	0	0	10	0	0	0	0	12	0	0	0	0	1	0	0	0	0
42-43	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	13	0	0	0	0	3	0	0	0	0
43-44	0	0	0	0	0	4	0	0	0	0	15	0	0	0	0	13	0	0	0	0	3	0	0	0	0
44-45	0	0	0	0	0	3	0	0	0	0	15	0	0	0	0	10	0	0	0	0	4	0	0	0	0
45-46	0	0	0	0	0	3	0	0	0	0	10	0	0	0	0	7	0	0	0	0	4	0	0	0	0
46-47	0	0	0	0	0	4	0	0	0	0	5	0	0	0	0	4	0	0	0	0	4	0	0	0	0
47-48	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0
48-49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49-50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50-51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51-52	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52-01	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTALS	177	0	0	0	0	24	8	0	0	0	121	0	0	0	0	129	1	0	0	0	29	0	0	0	0

Figure 6.3

PROGRAM IN LOGISTICS
INSTITUTE FOR MANAGEMENT SCIENCE AND ENGINEERING
THE GEORGE WASHINGTON UNIVERSITY

CSM#1 53 EXCESS CLASS CAPACITIES 05/07/76

PHASE	FROM	TO	YR1	YR2	YR3	YR4	YR5	TIJ	PH
ADVANCED JET-CHASE	B27	C45	5	6	0	0	0	18	3
ADVANCED JET-CHASE	B28	C46	2	6	0	0	0	19	3
ADVANCED JET-CHASE	B29	C46	6	7	0	0	0	17	3
ADVANCED JET-CHASE	B30	C47	6	7	0	0	0	17	3
ADVANCED JET-CHASE	B31	C48	4	7	0	0	0	17	3
ADVANCED JET-CHASE	B32	C49	3	0	0	0	0	17	3
ADVANCED JET-CHASE	B33	C50	5	0	0	0	0	17	3
ADVANCED JET-CHASE	B35	C52	4	0	0	0	0	17	3
ADVANCED JET-CHASE	B36	C01	3	0	0	0	0	17	3
ADVANCED JET-CHASE	B40	C06	1	0	0	0	0	18	3
ADVANCED JET-CHASE	B41	C07	1	0	0	0	0	18	3
ADVANCED JET-CHASE	B42	C09	1	0	0	0	0	19	3
ADVANCED JET-CHASE	B50	C23	5	0	0	0	0	25	3
BASIC JET-KINGSVILLE	A15	D41	5	0	0	0	0	26	4
BASIC JET-KINGSVILLE	A16	D41	3	0	0	0	0	25	4
BASIC JET-KINGSVILLE	A21	D44	6	0	0	0	0	23	4
BASIC JET-KINGSVILLE	A22	D45	6	0	0	0	0	23	4
BASIC JET-KINGSVILLE	A23	D46	6	0	0	0	0	23	4
BASIC JET-KINGSVILLE	A24	D47	6	0	0	0	0	23	4
BASIC JET-KINGSVILLE	A25	D48	1	4	4	4	4	23	4
BASIC JET-KINGSVILLE	A26	D48	4	0	0	0	0	22	4
BASIC JET-KINGSVILLE	A27	D49	2	0	0	0	0	22	4
BASIC JET-KINGSVILLE	A28	D51	6	0	0	0	0	23	4
BASIC JET-KINGSVILLE	A29	D52	1	0	0	0	0	23	4

Figure 6.4

Collectively, these outputs could provide a rich body of data for staff analyses, thereby forming a quantitative bases for making decisions. Data of this kind could be used as milestones to check whether production is ahead or behind; as an aid to better pipeline balancing of capacities; and as a mechanism for evaluating alternative student input schedules or other scheduling policies.

6.2 Scenario No. 1

A summary of the shortfalls computed by the DSFM for FY76 and the transition quarter of JUL-SEP 1976 is given below. There were no shortfalls for the later years through FY80.

JET: 30 PROP: 9 HELO: 0 TOTAL: 39

A special DSFM run was made leaving the student input schedule open and considering the resultant schedule as part of the solution. The comparative results are given in Figure 6.5. While the difference in the input schedules may not appear dramatic, the number of student holdover weeks (pooling) are substantial as indicated in Figure 6.6. A summary of these holdovers is listed in Figure 6.7 by the phase just completed. A more detailed listing of the holdovers is contained in Figure 6.8 where the breakdown is by month both for the scheduled student inputs and those computed by the DSFM.

Figure 6.9 is a summary of the unused capacities in the different pipelines.

6.3 Scenario No. 2

A summary of shortfalls computed by the DSFM is tabulated in Figure 6.10. The total is 351. An additional run was made without the requirement for uniform monthly output. From experience it was known that laying on this requirement had its penalties. The results of the run requiring only annual PTRs are given in Figure 6.11. The total is 109 shortfalls.

STUDENT INPUTS FY76 AND TQ77

MONTH	SCHEDULED	CALCULATED
JAN	31	9
FEB	100	81
MAR	118	138
APR	153	151
MAY	133	150
JUN	135	124
JUL	154	140
AUG	120	61
SEP	83	0

Figure 6.5

STUDENT HOLDOVERS
(THROUGH FY 77)

	SCHEDULED INPUT	CALCULATED INPUT
PRIMARY	609	336
JET	724	637
PROP	506	449
HELO	578	578
	2417	2000

48.34 STUDENT-YEARS LOST TO HOLDOVERS

8.34 SAVED BY IMPROVED STUDENT INPUT SCHEDULING

COULD ALSO MINIMIZE HOLDOVERS BY IMPROVING:

A. BALANCE OF PHASE CAPACITIES IN PIPELINES.

B. UNIFORM DISTRIBUTION OF WEEKS-TO-GO IN PHASE.

Figure 6.6

STUDENT HOLDOVERS

	FY76	TQ77	FY77	TOTALS
PRIMARY	219	260	130	609
BJ - CHASE		50	37	87
BJ - KINGSVILLE	37	170	104	311
BJ - MERIDIAN	53	158	44	255
BJ - PENSACOLA	15	42	14	71
BJ - TOTAL				724
BASIC PROP	282	203	21	506
PRE-HELO PROP	311	121	53	485
PRIMARY HELO	25	52	16	93
TOTAL HELO				578
TOTALS	942	1056	473	2417

Figure 6.7

STUDENT HOLDOVERS

		Primary		BJ-Chase		BJ-Kingsville		BJ-Meridian	
		SI	UI	SI	UI	SI	UI	SI	UI
FY76	JAN	28	28						
	FEB	55	55						
	MAR					3	3	5	5
	APR	79							
	MAY	24				1	1	5	5
	JUN	33				33	33	43	43
TOTAL		219	83			37	37	53	53
TQ77	JUN	17		12	12	114	114	101	101
	AUG	72		28	27	51	50	50	50
	SEP	171	86	10		5		7	7
TOTAL		260	86	50	39	170	164	158	158
FY77	OCT	125	158	9	1	10		4	2
	NOV	5	9						
	DEC								
	JAN								
	FEB								
	MAR						4		
	APR			1		13	54	3	19
	MAY			21	18	70	7	29	8
	JUN			6	6	11		8	
	JUL								
	AUG								
	SEP								
TOTAL		130	167	37	25	104	65	44	29

SI = Holdovers resulting from using the scheduled student input into Primary.

UI = Holdovers resulting from using student input determined as part of the solution to the dynamic student flow problem.

Figure 6.8a

	STUDENT HOLDOVERS						T-362	
	BJ-Pensacola		Basic Prop		Pre-Helo Prop		Primary Helo	
	SI	UI	SI	UI	SI	UI	SI	UI
FY76 JAN					2	2	7	7
FEB					7	7	6	6
MAR			1	1	18	18		
APR	7	7			4	4		
MAY	1	1	58	58	62	62		
JUN	7	7	223	223	218	218	12	12
TOTAL	15	15	282	282	311	311	25	25
TQ77 JUN	27	27	154	151	108	108	27	27
AUG	14	14	28				25	25
SEP	1	1	21	4	13	13		
TOTAL	42	42	203	155	121	121	52	52
FY77 OCT			6	6	35	35	13	13
NOV			3	3	12	12	3	3
DEC	1				4	4		
JAN	1				2	2		
FEB	1		7	2				
MAR	1		5	1				
APR								
MAY	7	7						
JUN	3	3						
JUL								
AUG								
SEP								
TOTAL	14	10	21	12	53	53	16	16

SI = Holdovers resulting from using the scheduled student input into Primary.

UI = Holdovers resulting from using student input determined as part of the solution to the dynamic student flow problem.

Figure 6.8b

UNUSED CAPACITY IN STUDENT WEEKS

	FY76	TQ77	FY77	FY78	TOTALS
PRIMARY/BASIC	647	182	84	124	1037
PROP	189	0	354	553	1096
JET - CHASE	126	5	265	355	
JET - KINGS	155	0	356	469	
JET - MERID	139	0	221	26	
JET - PENSA	53	9	109	100	
TOTAL JET	473	14	951	950	2388
TOTAL UNUSED CAPACITY					4521

Figure 6.9

SHORTFALLS IN SCENARIO NO. 2

	FY76 & 7T	FY77	FY78	FY79	FY80
JET	35	36	17	0	0
PROP	6	0	8	13	15
HELO	0	106	43	36	36
SUM	41	142	68	49	51

Shortfalls with Uniform Monthly PTRs

Figure 6.10

SHORTFALLS IN SCENARIO NO. 2

	FY76 & 7T	FY77	FY78	FY79	FY80
JET	35	36	0	0	0
PROP	6	0	0	0	0
HELO	0	32	0	0	0
SUM	41	68	0	0	0

Shortfalls Without Uniform Monthly PTRs

Figure 6.11

The solution requiring uniform monthly outputs contained 9,276 student weeks in pools. Of this amount, 2,512 student weeks were delays in starting the Primary or Basic Phase.

The solution not requiring uniform monthly outputs contained 7,020 student weeks in pools. Of this amount, 3,461 student weeks were delays in starting the Primary or Basic Phase.

The requirement for uniform monthly outputs costs 45 student years in pools over a five-year period. The pool of students awaiting entry into the Primary or Basic Phase could be virtually eliminated through improved student input scheduling.

6.4 Benchmark

One benchmark was made among the predictions of the HOWGOZIT [1] and the DSFM and the actual experience as of 21 March 1976 as reported in the Weekly Aviation Statistical Report (WASR). The results are given in Figure 6.12. The agreement is extraordinarily close. It is considered that such close agreement in any general use of these models should not be expected.

As of 3/21/76:

	JET	PROP	HELO
Experience as reported in the WASR	331	278	351
HOWGOZIT projection made last fall	341	262	352
CRISIS MANAGEMENT SYSTEM projection made 1/5/76	334	266	353

A Benchmark

Figure 6.12

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